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AN INTERNATIONAL COMPARISON OF THE ECONOMICS OF BUILDING INTEGRATED PV IN DIFFERENT RESOURCE, PRICING AND POLICY ENVIRONMENTS: THE CASES OF THE U.S., JAPAN AND SOUTH KOREA

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ABSTRACT

In recent years, the Center for Energy and Environmental Policy (CEEP), working with affiliated academic and research institutions in the U.S. and East Asia, has investigated the technical and economic feasibility of using dispatchable photovoltaic (DPV) systems in distributed peak-shaving (PS) applications. In each case, modest amounts of battery storage are used in conjunction with a PV array to achieve firm peak shaving for commercial building operators. Recent investigations have added emergency power as a second function of DPV-PS systems installed on commercial buildings.

This paper reports on CEEP's latest studies carried out in the US, Japan and South Korea which offer a cross-national review of the performance of dual-function DPV systems designed to serve peak shaving and emergency power needs of the commercial buildings sector. The market assessment results for each country are derived from *PV Planner*, a spreadsheet analytical tool developed at CEEP to run simulations of building integrated PV applications under different resource, pricing and policy environments. The analyses in all three countries rely on electricity load data from actual buildings, resource data for specific national locations, and actual electricity tariffs in use in each country. The paper recommends policies that can enable PV to compete as an energy service application in an international market.

1. BACKGROUND

The commercial buildings sector in the U.S. has emerged as a potential market for PV applications. In the early 1990s, the U.S. Department of Energy supported the development of an integrated DPV peak shaving (DPV-PS) system for the commercial buildings sector through their PV:BONUS Program. The system utilized modest amounts of battery storage in conjunction with a PV array to achieve firm peak-shaving for commercial building operators.

Several demonstration projects in the U.S. established the technical feasibility of DPV-PS systems (Byrne, et al, 1997). The development of these systems involved the collaborative effort of several organizations: Conectiv, a Mid-Atlantic electric utility (formerly known as Delmarva Power); the Center for Energy and Environmental Policy (CEEP); and Applied Energy Group (AEG), a utility consulting firm with experience in design and building-integrated PV systems and overseeing their installation.

National policies in Japan have strongly encouraged so-called roof-top PV applications.[1] Even though the full potential of PV is yet to be realized, installed capacity is rapidly growing. According to the New Energy Development Organization (NEDO),[2] the total generation capacity increased from 4MW in 1992 to 35MW in 1996. Japan has the second largest installed PV capacity behind the USA. As is the case in other countries, the major obstacle in promoting PV systems in Japan has been the high capital installation cost. Although the cost of PV has decreased as installed capacity increased, the cost is still several times higher than that of conventional electricity.

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[1] Japan's history of R & D in renewable energy is traced back to the early 1970s when the first oil shock threatened the national energy security. The Japanese government established a national strategy of strengthening energy security through energy conservation and alternative energy development.

[2] New Energy Development Organization (NEDO), a government-sponsored institute, was established in 1980 to promote and support the activities related to new and renewable energy development

South Korea's rapid economic growth during the last three decades has spurred even more rapid increases in energy demand. Lacking in domestic energy sources, South Korea has had to meet most of its energy needs by fuel imports from abroad. Such an imbalance between domestic energy sources and demand has left the country vulnerable to supply disruptions. In addition to this energy security problem, excessive consumption of fossil fuels inevitably brought about significant environmental degradation. Recognizing that the two major problems of energy security and environmental degradation are rooted in too much dependence on imported fossil fuels, the South Korean government recently initiated a national strategy for alternative energy development that includes new energy sources. Photovoltaics is one of the strategic items seriously considered in this strategy.

CEEP has conducted detailed studies in the U.S. to assess the market potential of DPV-PS systems including investigations of emergency power as an added value to such systems--designated DPV-PS/EP in this paper--installed on specific building types. (Byrne, Agbemabiese and Redlin, 1997; Byrne et al, 1997).[3] The concept of dual function DPV-PS/EP systems and the methodology for its evaluation have been developed over the last seven years at CEEP. These are briefly described below.

2. CONCEPTS AND METHODOLOGY

PV systems can be credited with both energy value (the system's ability to save energy) and capacity value (in the form of coincident peak demand reduction) (see Byrne et al, 1997). Generally, the economic viability of such systems is a function of the solar resource, existing policy incentives, the conversion technology, utility prices and customer demand characteristics. Equation (1) summarizes how the net present value of the system may be estimated:[4]

$$V_M = [P_D*(O_{kW} + O_{BAT}) + (P_E * O_{kWh})] - K_{PV} \quad (1)$$

where,

V_M = Net economic value of DPV-PS System
P_D = Utility demand (capacity) Price
O_{kW} = PV output at time of building peak demand (kW)
O_{BAT} = Battery bank output (net round trip losses) at time of building peak demand kW) [5]
P_E = Utility energy price ($/kwh)
O_{kWh} = Building PV Output (kWh)
K_{PV} = Capital costs of the PV energy management system[6]

When the economics of building-integrated PV is largely determined by a system's peak-shaving capacity value, the required storage can also be used to offer emergency power services to the building operator. This affects the economics of PV in an important way: only the additional capital cost of the PV array must be justified. We assume that the costs of battery storage, the inverter, and controls have already met an economic performance criterion for the building under evaluation. Accordingly, the payback period for a DPV-PS/EP system would depend upon the capital costs of the PV array itself, while balance of systems costs would be offset by the benefit of EP functionality in the system. Consistent with the preceding assumptions, the PV system payback period may be determined by subtracting tax credits (if any), annual net tax benefits, annual energy savings, and annual demand savings from the initial cost of the PV array. Equation (2) summarizes the net value of a DPV-PS/EP to a building:

$$V_S = [(B_{EP} - C_{EP}) + V_M] - C_{PV} \quad (2)$$

where,

V_S = Net economic value of DPV PS/EP system,
B_{EP} = Customer designated benefits of EP
C_{EP} = EP system cost (equivalent to BOS cost of a conventional PV system)
V_M = Energy management value of DPV-PS System, as defined in Equation (1)

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[3] PV systems with combined peak-shaving and emergency power functionality are referred to below as DPV-PS/EP applications.

[4] All economic terms have been discounted to reflect the time value of benefits and costs to the building owner.

[5] The O_{BAT} term represents the output of the battery bank at the time the building is experiencing its peak demand. It is a function of the size of the battery bank and the number of dispatch hours needed to assure shaving the peak load of the building.

[6] Includes PV array, mounting structure, inverter and battery storage. Tax benefits are accounted for in the analyses by means of appropriate deductions from these costs.

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C_{PV} = Cost of PV array and mounting structure

On the basis of Equation (2), cross-national market assessments were prepared using PV *Planner* an analytical tool developed at CEEP. The model was used to simulate the performance of a PV system operating as a dispatchable unit (i.e. with battery storage) with emergency power and peak-shaving capabilities. Overall economic performance in each simulated case is expressed in terms of benefit-cost ratios and payback periods. These evaluation criteria were calculated from a customer's perspective and were based on standard accounting procedures that are common to electricity markets in the U.S., Japan and South Korea.

Economic benefits included bill savings (in the form of reduced monthly energy and capacity charges) and tax credits and tax savings (from depreciation, loan interest deductions and tax credits) on capital investment. Costs included installed capital costs of all equipment and O&M expenditures. In the South Korean case, benefits and costs were discounted at a real rate of 5% (net of inflation) and aggregated into net present values (NPVs). In the U.S. and Japanese cases, real discount rates of 7.5% and 2.2% respectively, were used. These rates are based on discussions with investors in electricity markets. Table 1 summarizes other principal variables that were used in the analysis.

3. SUMMARY OF CROSS-NATIONAL FINDINGS

Our findings on the performance of DPV-PS/EP systems installed in the three case study countries are based on the operation of 10kW arrays with typical storage requirements of approximately 50kWh (storage is set equal to the amount of energy provided on the peak day and, therefore, varies by country and location, based on insolation). The analyses assumed that modest amounts of storage capacity were reserved in the DPV-PS system for emergency power (EP) applications. Earlier studies in the U.S. had shown that the economic viability of such dual-purpose systems can be substantial for building owners.

TABLE 1: COMPARISON OF KEY VARIABLES

Policy Variable	**USA**	**Japan**	**Korea**
Solar Resource (kWh/m^2)	.20 – 24	.35	.40
Dispatch Hours[7] (Hours)	2 – 4	2 - 4	3
PV System Features			
Array[8] cost/kW	$7500/kW	$8700/kW	$8700/kW
Battery cost/kWh	200/kWh	200/kWh	200/kWh
Tax Incentives			
Tax Credits (Nat'l)	10%	15%	15%
Tax Credits (State)	35%		
Rate Structure			
Energy Charge (¢/kWh)	0 – 71	19.03	16.10
Demand Charge ($/kW)	0 – 45.6	13.10	6.70
Financial Incentives			
Loan Limit	NA	50-60%	90%
Depreciation	5 yrs.	5 yrs.	1-5 yrs.

U.S. Case Studies

CEEP undertook a market assessment based on simulation runs of DPV-PS/EP systems installed on office buildings within 11 utility areas in the U.S. The results are shown in Table 2. The benefit-cost ratios and payback periods represent the near-term market for dispatchable peak-shaving PV systems configured to provide peak shaving and emergency power functions in the commercial buildings sector.

These results indicate that North Carolina (Duke Power and Crescent Electric Membership Co.) offers the highest potential for cost-effective DPV-PS/EP system installations. This is attributable to the 35% renewable energy investment tax credit offered in the state. Together with a 10% federal tax credit, building owners in North Carolina thus enjoy 45% tax savings on capital costs of DPV-PS/EL systems. In fact, benefit-cost ratios greater than or equal to 1.00, were observed for large office buildings in all jurisdictions when emergency power functionality was also included. This means that building-integrated PV can be expected to be cost effective at current installed PV system prices (excluding storage) of $8.70 per Wp if emergency power service is needed.

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[7] Set at intervals that maximize peak shaving.

[8] 10 kW array size assumed in all cases.

Japanese Case Studies

CEEP has also analyzed the cost-effectiveness of installing 10kW DPV-PS/EP systems for three building types: office building, hotel, and department store in the Tokyo area. Although this analysis showed that the DPV-PS/EP systems could not achieve cost-effectiveness under base case assumptions (which exclude tax credits or subsidies), it was found that with modest policy support this technology would become economically feasible.

TABLE 2: BCRS AND PAYBACK PERIODS FOR DPV-PS/EP APPLICATIONS IN SELECTED UTILITY JURISDICTIONS IN THE U.S.

Utility	BCR	PBP
BOSED	1.08	4
CONED	1.23	3
LILCO	1.30	3
DP&L	1.03	4
NMPC	1.07	4
SOCALED	1.07	4
PG&E	1.06	4
CRESCENT	1.47	1
DUKEPOWER	1.43	1
AUSTIN	1.04	4

The value of a tax credit needed to make the PV system cost-effective varied by building type. Our analysis shows that a tax credit of less than 10% is needed to realize net benefits from DPV-PS/EP in Japan. The Japanese government currently offers 7% tax credit. The critical value for a capital cost subsidy based on the assumption of no tax credit is about 22% for all building types. The Japanese government provides a 50% capital cost subsidy that should be more than enough to make the system competitive in the market.

Benefit-cost ratios and payback periods calculated to include the value of emergency power service shows again that DPV-PS/EP is cost-effective at current PV prices. The results are given in Table 3. Since the competitiveness of PV systems can be enhanced by such things as tax and loan incentives, a sensitivity analysis was conducted to evaluate the impacts of different policy options. Two policy instruments— tax credits and capital cost subsidies— were considered.

TABLE 3: BCRS AND PAYBACK PERIODS FOR DPV-PS/EP APPLICATIONS FOR SELECTED BUILDING TYPES IN TOKYO, JAPAN

Building	BCR	PBP
Office Building	1.32	2
Downtown Hotel	1.40	2
Dept. Store	1.35	2

Korean Case Studies

CEEP cooperated with the Korea Institute of Energy Research (KIER), to evaluate the cost-effectiveness of DPV-PS/EP systems for three building types—a large office complex, a department store and a downtown hotel—in two major Korean cities (Seoul and Taejon).

Commercial building owners in Korea investing in renewable energy technologies are eligible for an annual 15% investment tax credit during the first three years of operation. In addition, full depreciation of the capital cost of the system is possible in the first year of operation. The latter tax benefit is available for all major capital equipment investments. Such tax treatment has advantages for high capital cost technologies like PV. Table 4 shows the favorable benefit-cost ratios and payback periods that result. In all cases, the BCRs are well above 1.00, indicating that DPV-PS/EP is cost-effective at current installed system prices. A payback period of two years also indicates that investment in these PV applications are competitive.

TABLE 4: BCRS AND PAYBACK PERIODS FOR DPV-PS/EP APPLICATIONS FOR SELECTED COMMERCIAL BUILDING TYPES SEOUL AND TAEJON

Building	BCR	PBP
Seoul Office	1.70	2
Seoul Hotel	1.46	2
Seoul Store	1.37	2
Taejon Office	1.73	2
Taejon Hotel	1.72	2
Taejon Store	1.62	2

4. POLICY IMPLICATIONS

Despite significant policy and resource differences, all systems are cost-effective. Our cross-national review suggests that a variety of opportunities exist for the market penetration of such DPV-PS/EP systems.

Tax incentives had the greatest impact on BCR. In the U.S., the addition of the 35% state tax to the federal credit of 10% increased BCR by an average of 31%. In the Japanese case, an increase in incentives from 0% to 45% would increase BCR by 30%. In Korea the average BCR increased by 52% for a similar 45% increase in tax incentives.

Rate structure was another important factor affecting BCR. In all the cases studied, the avoided costs to building owners—and hence the value of the BCR—were consistently higher for rate structures characterized by relatively high demand charges. DPV-PS/EP systems operating within the New York jurisdictions of LILCO and CONED yield higher BCRs than those in California and Texas (1.23 and 1.30, respectively) under current market conditions for the building types covered in this study (i.e. assuming no extra tax incentives beyond the 10% federal tax credit).

Emergency power is the third major factor that contributes to making DPV-PS/EP cost-effective. It affects payback period in particular since the costs of battery storage, the inverter, and controls are excluded, by definition, from the calculation of this criterion in a DPV-PS/EP. In the U.S., earlier studies showed that the value added by addition of emergency power is up to 7% on average (Byrne et al, 1997). The importance of adding emergency power functionality is clearly demonstrated in the Japanese and Korean cases with increases in value added up to 44% and 63% respectively.

5. CONCLUSION

A DPV-PS/EP system represents an alternative philosophy of energy use that emphasizes service rather than, simply, electrical supply. A combination of tax incentives, rate structure and financial incentives appears particularly favorable to the operation of dual-function DPV-PS/EP systems in parts of the U.S., Japan, and Korea where payback periods are less than 5 years in all cases.

At current prices a tax credit of between 15 and 45%, will support accelerated penetration of such systems into the U.S., Japanese and Korean markets. To promote photovoltaics as a viable technology in the buildings sector, existing energy policy needs to be re-thought to reward service-oriented applications such as those examined in this paper.

7. REFERENCES

(1) Byrne, J., S. Letendre, L. Agbemabiese, D. Redlin and R. Nigro, Commercial Building Integrated Photovoltaics: Market and Policy Implications. Proceedings of the 26th IEEE Photovaltaic Specialists Conference, 1997
(2) Byrne, J., S. Letendre, L. Agbemabiese, D. Bouton, J. Kliesch, D. AitkeN, Photovoltaics as an Energy Services Technology: A Case of PV Sited at the Union of Concerned Scientists Headquarters, Proceedings of the American Solar Energy Society Solar 98 Conference, 1998
(3) Letendre, S., C. Weinberg, J. Byrne and Y-D Wang, Commercializing Photovoltaics: The Importance of Capturing Distributed Benefits. Proceedings of the American Solar Energy Society Solar 98 Conference, 1998.
(4) Byrne, J., S. Letendre, C. Govindarajalu, R. Nigro, and Y-D. Wang, Evaluating the Economics of Photovoltaics in a Demand-Side Management Role, Energy Policy, Vol. 24, No.2 (February): 177-185, 1996
(5) Byrne, J., R. Nigro, and Y-D. Wang, Photovoltaic Technology as a Dispatchable, Peak-Shaving Option, Public Utilities Fortnightly, 1996
(6) Center for Energy and Environmental Policy, PV Planner: A Spreadsheet Analytical Tool for Grid-Connected Applications, Report submitted to the National Renewable Energy Laboratory, 1996.